Crawford, C. S., and R. C. Krehoff. 1975. Diel activity in sympatric populations of the scorpions *Centruroides sculpturatus* (Buthidae) and *Diplocentrus spitzeri* (Diplocentridae). J. Arachnol. 2:195-204.

DIEL ACTIVITY IN SYMPATRIC POPULATIONS OF THE SCORPIONS *CENTRUROIDES SCULPTURATUS* (BUTHIDAE) AND *DIPLOCENTRUS SPITZERI* (DIPLOCENTRIDAE)[1]

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ABSTRACT

Field observations of sympatric *Centuroides sculpturatus* and *Diplocentrus spitzeri* scorpions in the Peloncillo Mountains in New Mexico revealed that during the warmer months nocturnal extra-rock surface activity was relatively great in the former species. In contrast, *D. spitzeri* tended to remain beneath rocks near the openings of its burrows. During the day *C. sculpturatus* also used the rocks as shelter, clinging to the underside. Actograph studies of both species showed them both to have nocturnal activity when imposed photoperiod was the only variable; however, only *C. spitzeri* displayed an endogenous circadian rhythm in constant darkness.

Rooftop observations of *D. spitzeri* confined to containers, each with soil and a rock for shelter, indicated that under poor shelter conditions extra-rock nocturnal activity is common for early instars through adults. In another rooftop study *D. spitzeri* adults exhibited random choice of available rock shelter.

It was concluded that different spatial and temporal strategies may make possible avoidance of competition between these two species.

INTRODUCTION

The dichotomous terms "bark" scorpion and "ground" scorpion have been used to roughly describe scorpion behavior in relation to habitat. Stahnke (1966) points out that the highly venomous buthid *Centruroides sculpuratus* is a bark scorpion because it occurs frequently under loose tree bark; when hiding under rocks it often displays negative geotaxis by clinging to the underside. Like other bark scorpions, it has a tendency to enter crevices.

In parts of the Peloncillo Mountains in southwestern New Mexico *C. sculpturatus* is sympatric with the diplocentrid ground scorpion *Diplocentrus spitzeri* (Figs. 1, 2). Nine visits were made to the area between February, 1972 and January, 1974; all seasons were covered. During each visit, which lasted at least two days, hundreds of rocks were raised in a search for *D. spitzeri* and a species of centipede, both of which were being analyzed for cold-hardiness development.

[1] Supported in part by NSF grant GB-31602.

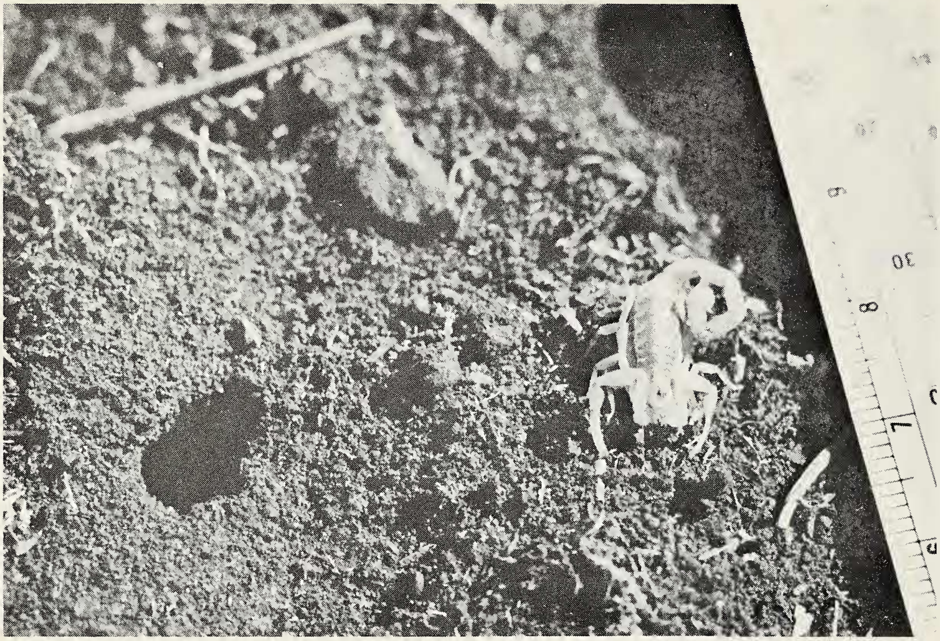

Fig. 1.–Immature *Centuroides sculpturatus* directly following removal of its rock shelter. Peloncillo Mountains, New Mexico.

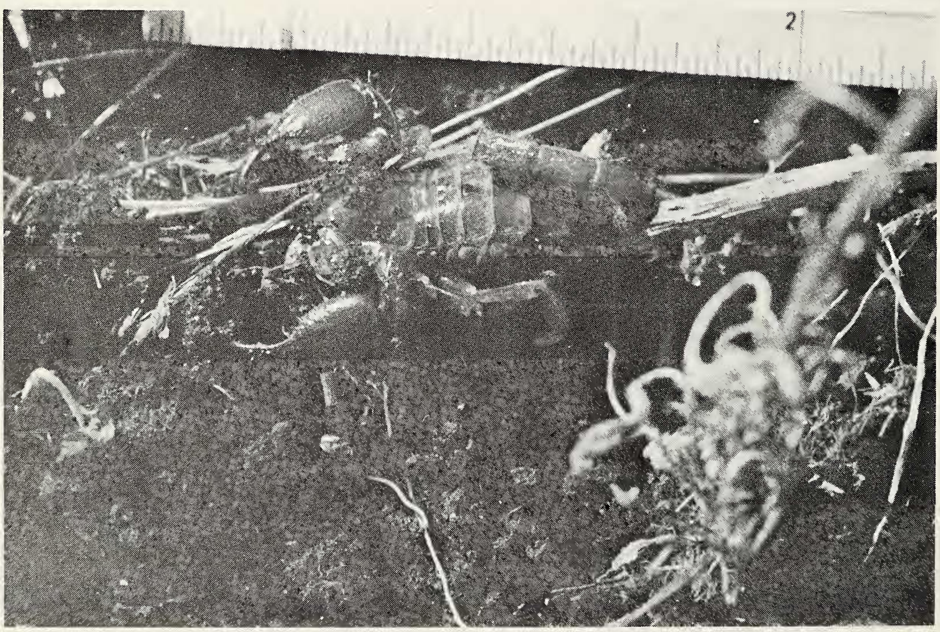

Fig. 2.–Adult female *Diplocentrus spitzeri* directly following removal of its rock shelter. Peloncillo Mountains, New Mexico.

During the warmer months both scorpion species were found under exposed rocks on moderately grazed ridges and upland slopes at 1500-1800 m elevation (Figs. 3, 4). As

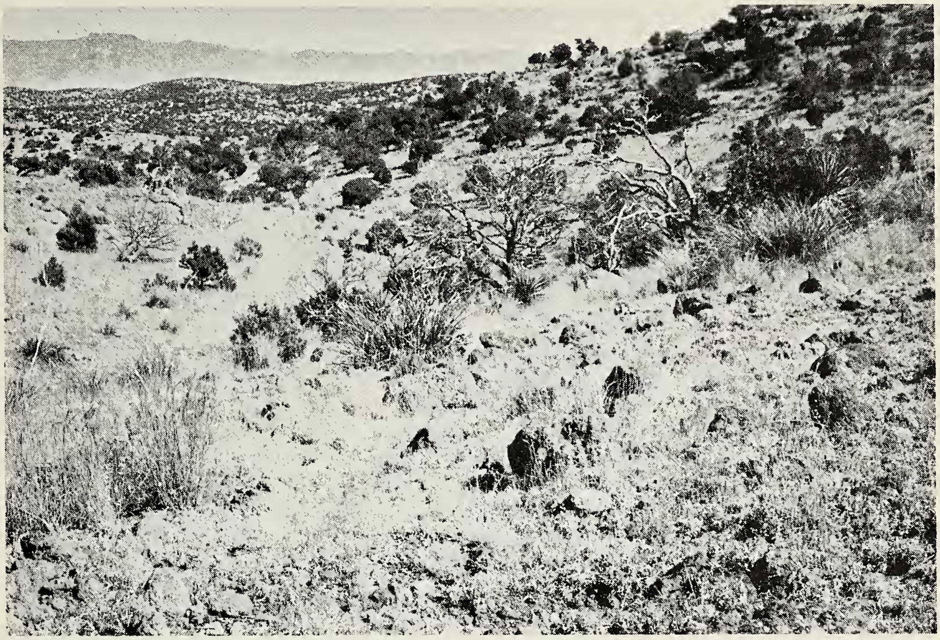

Fig. 3.–Typical habitat of both scorpion species in the Peloncillo Mountains, New Mexico.

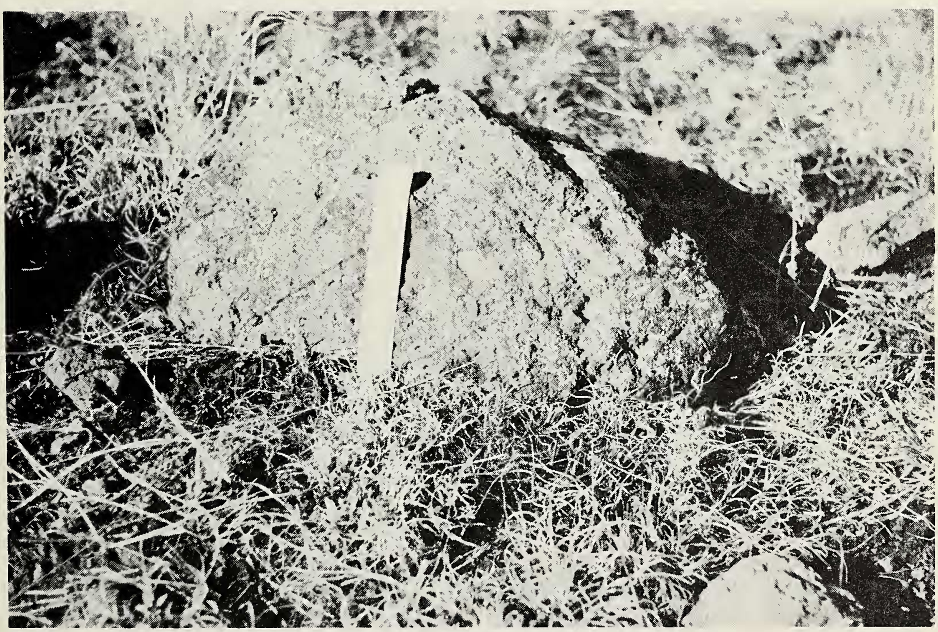

Fig. 4.–Rock typical of those affording shelter for both scorpion species in the Peloncillo Mountains, New Mexico.

with some other ground scorpions, *D. spitzeri* is an effective burrower and was most frequently seen at its burrow entrance beneath a rock. Thus, both species occupy the same general microhabitat during part of the year. The two are occasionally even encountered under the same rock.

Being scorpions, both species should be expected to prey on a variety of local arthropods (Cloudsley-Thompson, 1968; Stahnke, 1966; personal observations). If food and shelter are to some extent shared, then the question of competition—or of its avoidance—must be raised. This paper describes field observations that shed some light on this question, and also reports the results of rhythm studies designed to do the same.

Initially, we wished to characterize the diel periodicity of *D. spitzeri* relative to a possible association between photoperiod and cold-hardiness development (Crawford and Riddle, 1974). Therefore, the present study includes results of outdoor experiments performed with confined *D. spitzeri* and describing extra-rock activity at night.

FIELD OBSERVATIONS OF DIEL ACTIVITY—BOTH SPECIES

Field studies were usually conducted 1-5 km south of Geronimo Pass in the Peloncillo Mountains. Sporadic night collecting was undertaken using black lights. Results of six post-dusk excursions to the habitat in question are given in Table 1. Clearly, *C. sculpturatus* was the more common surface scorpion at night. All but two of the *D. spitzeri* seen were adults. Of the two species, there was a much greater immature: adult ratio in *C. sculpturatus*, although we made no actual counts of immatures.

Table 1.—Nocturnal surface observations of relative numbers of scorpions in the Peloncillos, made while continually walking back and forth over areas varying in size.

Date	Hours (MDT) of observation	Weather	No. of *D. spitzeri*	No. of *C. sculpturatus*
10-1-71	2245-2315	cool, windy	0	0
6-16-72	2115-2230	sultry, warm	7	> 20
6-18-72	2030-2230	warm	5	> 20
9-10-72	1200-2200	cool, moist	3	15
7-22-73	2030-2200	cool, dry	3	8
10-18-73	2000-2100	very cool	0	1

During hours of daylight no scorpions were seen except for those under rocks. The great majority of those seen were *D. spitzeri* and they were present all year long in or near their burrow entrances. *Centuroides sculpturatus* was never abundant in the daytime, and although it was not actually counted (because it was usually not being collected), it was encountered no more than once for every 10 or so *D. spitzeri* observed. As might have been expected (Stahnke, 1966), *C. sculpturatus* generally clung to the underside of the rocks that were raised.

ACTOGRAPH STUDIES OF DIEL LOCOMOTOR ACTIVITY—BOTH SPECIES

An attempt to characterize the influence of photoperiod relative to possible endogenous rhythms was made for both species in the absence of temperature variation. Following seven days of insectary conditioning at 26°C and the appropriate photoperiod eight recently collected scorpions of each species were placed in separate units of two actographs (Fig. 5). Fig. 6 indicates the photoperiods employed. The activity-measuring units consisted of large plastic petri dishes (diam 15 cm) balanced so that any movement of the scorpion within caused each dish to tilt. Each tilt of a dish in turn caused an electrical circuit to be either completed or broken, thus producing a needle deflection on one channel of an event recorder. Needle deflections were recorded on chart paper moving at 15 cm hr^{-1}. An 8-channel event recorder was used so that locomotor activity of eight animals could be analyzed at a time.

Activity was recorded for five days at an existing insectary photoperiod at 35°N at the time of year (autumn) an actograph run was made. Onset of each dark period began at 2100 hours. At the beginning of the sixth dark period actographs were covered with lightproof boxes for the following five days.

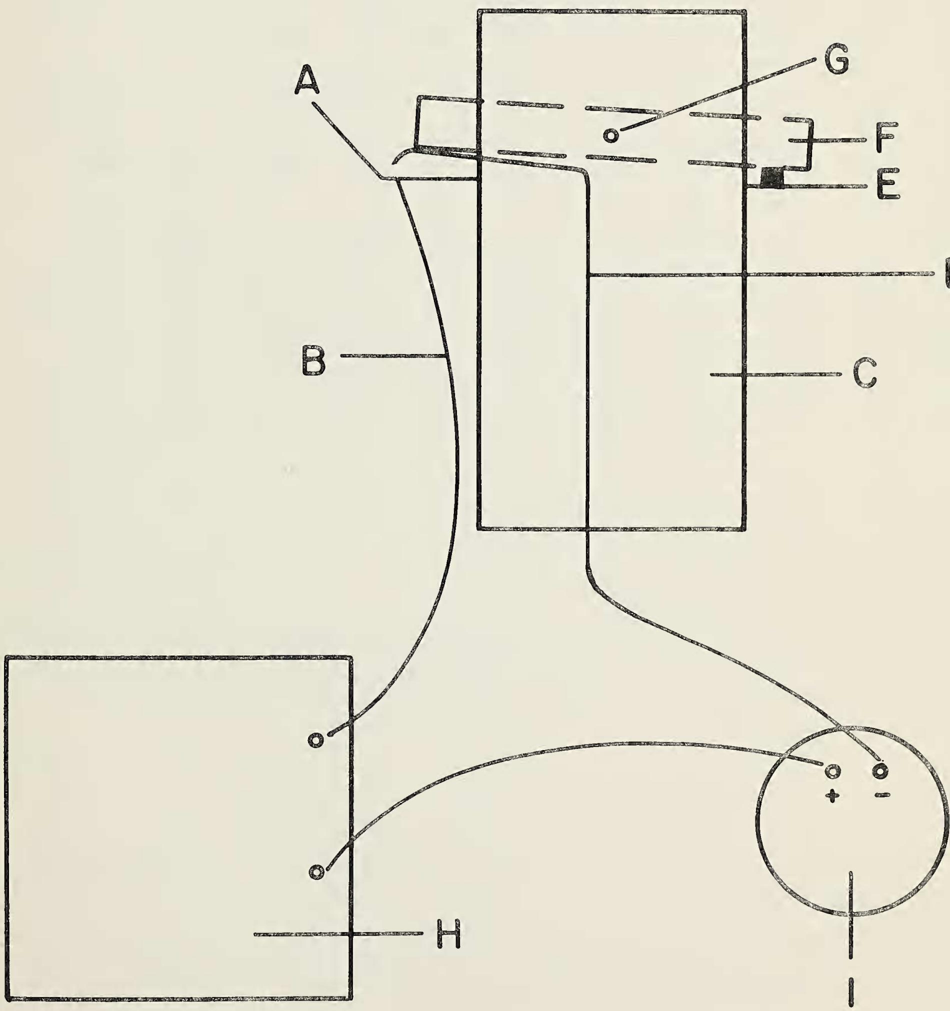

Fig. 5.–Diagrammatic representation of an actograph used to measure scorpion diel periodicity. A: copper plate, B: wire, C: wooden frame, D: wire, E: dish stop, F: petri dish, G: balancing pin, H: recorder, I: power supply.

Fig. 6 presents the results of the actograph tests. As expected from results of other activity-rhythm studies with scorpions, rhythms of locomotor activity in both species are nocturnal and are influenced by photoperiod. The presence of an endogenous circadian clock can be ascertained for *C. sculpturatus* because that species displayed a pronounced diel rhythm of activity in constant darkness. In contrast, a breakdown in the activity rhythm of *D. spitzeri* in constant darkness was soon apparent.

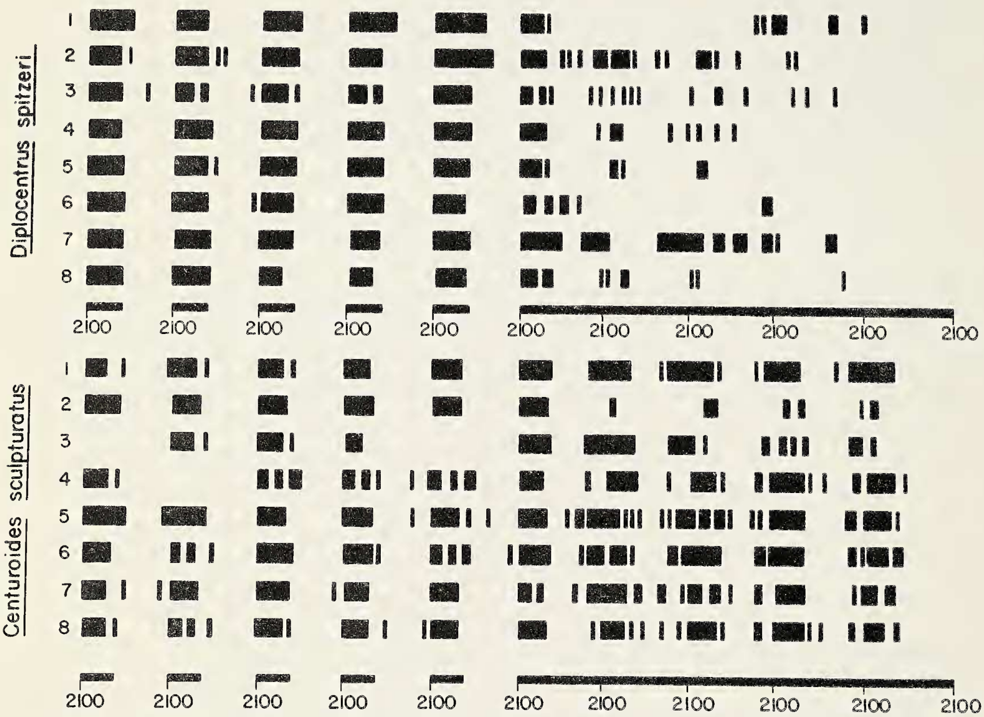

Fig. 6.–Condensed actograph records of eight acclimated *D. spitzeri* and eight acclimated *C. sculpturatus*. Acclimation consisted of a week of exposure to 26°C and the appropriate photoperiod. Five days of photoperiod (alternating black and white bars; LD 14:10 for *D. spitzeri* and 15:9 for *C. sculpturatus)* are followed by five days of constant darkness (long, black bars). The repeated values of 2100 on the horizontal axis refer to the time (MDT) at which a light-dark transition occurred during each photoperiod. Within each 24-hr period the black areas indicate the extent of activity (in excess of 1.5% of a possible day's total) that took place during any given hour.

ROOFTOP STUDIES OF DIEL ACTIVITY–*D. SPITZERI*

Observations in the field at night suggested that the influence of the sub-rock environment was generally strong enough in *D. spitzeri* to override exogenous and endogenous factors promoting surface exploration. We tested this idea by observing the extra-rock activity of specimens confined individually to buckets about 25 cm in diameter. The buckets were kept on the roof of the Biology Building at the University of New Mexico. They were covered by an elevated sloping roof of corrugated sheet metal that was designed to minimize heat buildup below and to keep off rain. Each bucket was one-third filled with habitat soil that was moistened periodically. A habitat rock averaging about 10 cm in diameter and 5 cm in height was placed centrally on the soil to provide a somewhat natural shelter. Beneath each rock a simulated burrow about 10 cm long was fashioned at a 45° angle.

Regular evening observations of adults, medium-sized juveniles, and second-instar specimens (seven of each) collected in June, 1972 are given in Table 2. Exploratory activity tended to begin shortly after sunset and to increase during the next hour. All scorpions considered in Table 2 were given mealworms (pieces of mealworm for small specimens) the afternoon of June 29, 1972.

Table 2.–Evening activity of *D. spitzeri* (seven in each group) in individual soil-filled buckets and exposed to natural photoperiod and temperature.

	No. of scorpions emerged from rock shelters								
	Sunset to sunset –15 min.			Sunset to sunset + 30 min.			Sunset + 30 min. to sunset + 60 min.		
Date (1972)	Adults	Juv.	2nd inst.	Adults	Juv.	2nd inst.	Adults	Juv.	2nd inst.
6-30	0	0	0	1	1	1	4	2	4
7-2	0	0	0	1	0	0	3	2	4
7-4	0	0	1	0	1	3	0	1	5
7-6	0	0	0	0	0	0	3	1	3
7-8	0	0	0	1	1	2	4	4	5
7-10	0	0	0	1	1	0	1	2	4
7-12	0	1	3	1	2	4	1	4	5

Two all-night studies were made of the same scorpions in late August and early September 1972 (except that three second-instars were missing by that time and that four adults were added in early August). The first night of observations was made 11 days after a mealworm feeding; the second was made four nights after the first and one day after a feeding. To check on feeding effectiveness all rocks were raised the morning following the second observation night. In nearly all cases at least some evidence of recent feeding was noted.

Respective times of sunset were 1935 and 1928 hours, while times of sunrise were 0639 and 0642 hours (MDT). Air temperatures ranged from about 17-25°C both nights, during which time there were intermittant breezes. A slight rain occurred the second night.

Table 3.–Nocturnal activity of *D. spitzeri* in individual soil-filled buckets and exposed to natural photoperiod and temperature, August 31-September 1, 1972.

	No. of scorpions emerged from rocks shelters			
Hour (MDT) beginning	Adults n=11	Juveniles n=7	2nd instar n=4	Total % active
1930	5	2	1	36
2030	8	3	2	59
2130	9	2	2	59
2230	10	3	2	68
2330	9	4	2	68
2430	9	4	2	68
0130	9	5	2	73
0230	7	3	2	55
0330	7	3	2	55
0430	6	2	2	45
0530	6	2	2	45
0630	4	0	1	23

Results of nocturnal-activity observations are condensed in Tables 3 and 4. They indicate that a majority of scorpions emerged from beneath their rock shelters on both nights. They also show that peak activity took place in the middle hours of both nights, and that all hours of darkness supported some activity. The extent of nocturnal activity so recorded is in agreement with the pattern recorded during an imposed photoperiod. No noticeable difference in activity that can be attributed to feeding is evident in Tables 3 and 4.

Table 4.–Nocturnal activity of *D. spitzeri* in individual soil-filled buckets and exposed to natural photoperiod and temperature, September 5-6, 1972.

Hour (MDT) beginning	No. of scorpions emerged from rock shelters: Adults n=11	Juveniles n=7	2nd instar n=4	Total % active
1930	9	3	1	59
2030	8	5	2	68
2130	8	6	1	68
2230	11	6	1	82
2330	10	6	1	77
2430	10	6	2	82
0130	7	4	1	55
0230	6	3	2	50
0330	3	4	2	41
0430	4	2	2	36
0530	2	2	2	27
0630	1	1	1	14

SHELTER-PREFERENCE STUDIES–*D. SPITZERI*

Because most of the life of *D. spitzeri* is spent in a burrow that opens directly beneath a rock, we questioned whether or not preference is shown for a particular rock. To test the possibility of preference we created an artificial habitat under the rooftop shelter. It consisted of a child's plastic swimming pool, about 0.3m high and 2 m in diameter, and partly filled with habitat soil. Ten habitat rocks measuring about 20 cm in diameter and 10 cm in height were placed on the surface so that they were equidistant from each other; none was closer to the container side than to another rock. Each was numbered with paint, and beneath each was a simulated burrow similar to the type described above.

For purposes of identification each of 10 adult scorpions except one was lightly spotted on the carapace with combinations of red, yellow, or white acrylic paint. On July 2, 1972 they were placed in the artificial habitat, each beneath a separate rock. Rocks were slightly raised on eight subsequent days in order to detect whatever final dispersion had taken place the previous night. Occasional nighttime visits to the shelter informed us that the scorpions wandered throughout the night; however, we did not note how many times (if at all) in a night each animal crawled under a given rock or emerged from beneath it.

Results of this experiment are given in Table 5. It is apparent that in only one case was a scorpion found beneath the same rock after more than two consecutive nights. In three instances the same sub-rock microhabitat was occupied by two specimens. Rock utilization was apparently random, with increasing use of the pool side as a "shelter" after the first night.

Table 5.—Shelter preferences of *D. spitzeri* in an artificial habitat of equidistantly placed rocks on habitat soil in a 6-m diameter container exposed to natural photoperiod and temperature. † = side of shelter.

Specimen	Rock number or other location where specimens were found during the day in July							
No.	3	4	5	6	7	9	10	11
1	10	9	9	†	†	7	9	†
2	5	6	†	8	†	†	†	†
3	6	1	8	6	†	†	†	†
4	7	†	†	†	†	†	†	†
5	2	2	2	7	7	†	8	8
6	8	5	5	5	5	5	†	8
7	9	3	†	1	†	8	1	1
8	3	10	†	9	9	3	7	3
9	4	7	7	8	†	9	†	9
10	1	8	†	6	8	†	†	†

DISCUSSION AND CONCLUSIONS

Our observations corroborate the well known fact that scorpions as a group are active nocturnally. Cloudsley-Thompson (1973) showed that regardless of varying abilities to resist water loss, three species of scorpion exhibited similar patterns of nocturnal locomotor activity. He used this information to support the view that scorpions have tended to become secondarily nocturnal for reasons not associated with water loss. In fact, rates of water loss for *C. sculpturatus* and *D. spitzeri* differ considerably at 30°C (Hadley, 1970; Crawford and Wooten, 1973), the former species being much more resistant to desiccation.

Our field observations consistently indicated that extra-rock nocturnal activity is more common in *C. sculpturatus* than in *D. spitzeri*. Therefore, a greater degree of spatial separation appears to occur at night than in the daytime when *C. sculpturatus* clings to the rock underside while *D. spitzeri* remains near its burrow entrance. Surface foraging has been described previously for *C. sculpturatus* (Hadley and Williams, 1968). In the Peloncillos this scorpion tends to move about at night, perhaps reflecting the hunting possibilities in a varied terrain. Such behavior is reminiscent of that shown by *C. sculpturatus* at Puerto Penasco, Sonora, in comparison to the scorpion's motionless presence on the desert surface in the Tempe-Mesa, Arizona area (Hadley and Hill, 1969).

The endogenous circadian rhythm of activity shown for *C. sculpturatus* seems typical of a number of scorpions (Cloudsley-Thompson 1956, 1963, and 1973). Entrainment of a circadian rhythm by existing photoperiod should be advantageous to predaceous arthropods that utilize food resources some distance from their diurnal shelters. The endogenous nature of this kind of movement has the potential disadvantage of bringing about exposure to nocturnal enemies. It also precludes daytime foraging in the reduced illumination of a shelter.

Such a circadian foraging pattern is apparently not the strategy to which *D. spitzeri* is restricted. Instead, this species seems to have the option of a potentially continuous period of foraging in its normally dark habitat. Our not infrequent daytime observations of its feeding on freshly killed arthropods (especially larvae and adults of Tenebrionidae) substantiate this view.

Although we did not satisfactorily demonstrate that foraging is related to hunger in *D. spitzeri*, there is little question that when the only available rock shelter is smaller than usual (and perhaps less appropriate in other ways as well) extra-rock foraging becomes a common event. This suggests that decreasing illumination perceived in an incompletely darkened sub-rock environment can provide sufficient stimulus to promote such behavior. Presumably, there are occasions in the natural habitat when *D. spitzeri* becomes exposed to this kind of illumination and responds accordingly. Another reason for leaving the shelter of small rocks may well be that they provide relatively little prolonged moisture for this moderately desiccation-resistant scorpion and for its prey as well. Departure from a rock shelter may enable *D. spitzeri* to find prey in the open, and to enter a new shelter before dawn. The occasional presence of two adults of the same sex beneath the same rock attests to this possibility.

Williams (1970) compared regional diversity of scorpion species with that of other arachnids and concluded that diversity is relatively restricted in the former group. He attributed this to the similarity of food sources, habitat requirements, morphology, and generalized behavior of scorpions, and contended that these could result in the competitive exclusion of all but a limited number of species within a regional fauna. On the other hand, according to Williams, there must be mechanisms that allow for species coexistence.

We conclude that in warmer months in the Peloncillo habitat, competition between *C. sculpturatus* and *D. spitzeri* for similar food and shelter may be avoided because of different spatial and temporal foraging strategies. An important physiological basis for this difference is the presence of an endogenous circadian rhythm of activity in the former species and its absence in the latter species. Competition is apparently avoided in the colder months because of species separation, as we found only one *C. sculpturatus* beneath a rock in winter, compared on an average of 15 or more *D. spitzeri* collected per winter day.

ACKNOWLEDGEMENTS

We wish to thank H. L. Stahnke for identifying the scorpions and W. A. Riddle for assistance in the field. Helpful criticism of the manuscript by W. A. Riddle and R. C. Wooten, Jr., is acknowledged.

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